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14. ABSTRACT
We have investigated and determined how the tensor properties of an impedance surface can be shaped to control and steer surface waves in a very general way, all the while preserving phase information. Two findings made this possible. First, it was discovered through eigenvalue analysis that a TM or TE surface bound wave tends to favor strongly propagation along one of the principal axes of its tensor impedance matrix. This is illustrated by the series of simulations shown in Figure 1 for the case of a TM wave, which favors propagation along the shorter principal axis.

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We have investigated and determined how the tensor properties of an impedance surface can be shaped to control and steer surface waves in a very general way, all the while preserving phase information. Two findings made this possible. First, it was discovered through eigenvalue analysis that a TM or TE surface bound wave tends to favor strongly propagation along one of the principal axes of its tensor impedance matrix. This is illustrated by the series of simulations shown in Figure 1 for the case of a TM wave, which favors propagation along the shorter principal axis. Figure 1b shows the propagation pattern that a small dipole array creates on a scalar impedance surface (isotropic). When the impedance is made anisotropic, with the shorter principal axis pointing in the propagation direction, energy propagates mostly in that direction and remains strongly confined to a beam shape, as shown in Figure 1a. But when the shorter axis is rotated to be perpendicular to the propagation direction, energy instead spreads out in the transverse direction, as shown in Figure 1c.

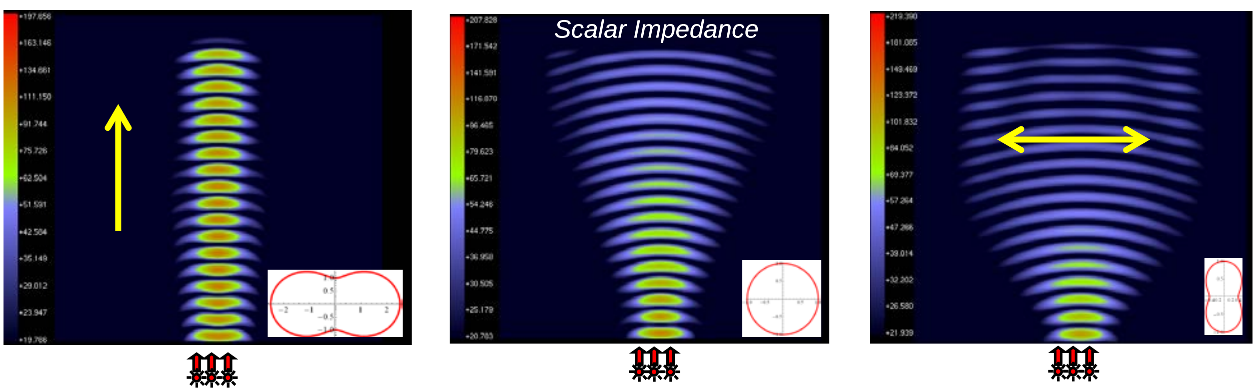


Figure 1: Tensor properties of impedance surface determine the wave propagation pattern.

(a) TM propagation along short principal axis of tensor impedance matrix. Energy remains focused like a beam along short axis direction.

(b) TM propagation for scalar impedance matrix.

(c) TM propagation along long principal axis of tensor impedance matrix. Energy spreads out in short axis direction.

We naturally attempted to exploit this property to steer a surface wave into an arbitrary direction. We hypothesized that by smoothly rotating the principal axis as we sweep across the surface (illustrated in Figure 2a), the mode corresponding to the new direction gets excited to divert energy towards this new direction. While energy does propagate in the intended direction, this approach alone is insufficient to rotate the wavefront towards the intended propagation direction, as shown by the simulation result in Figure 2b.

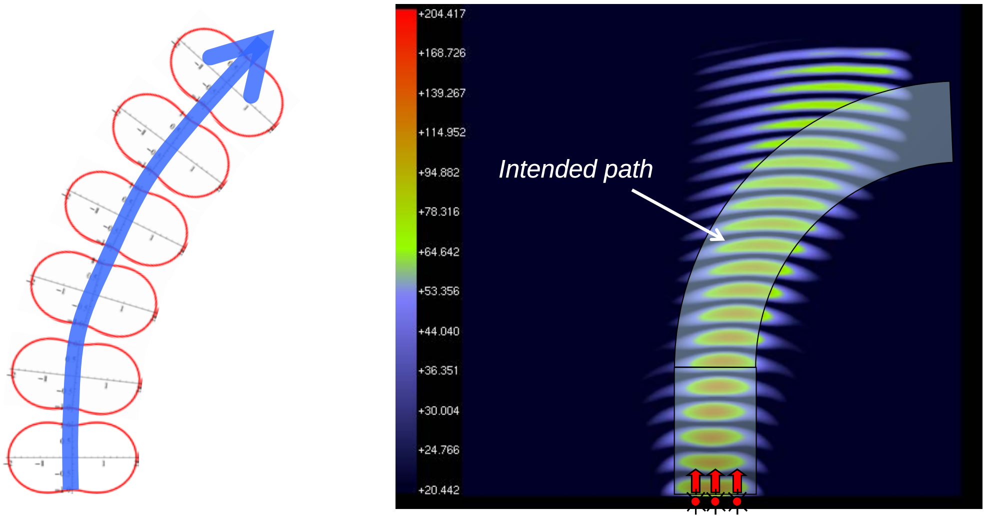
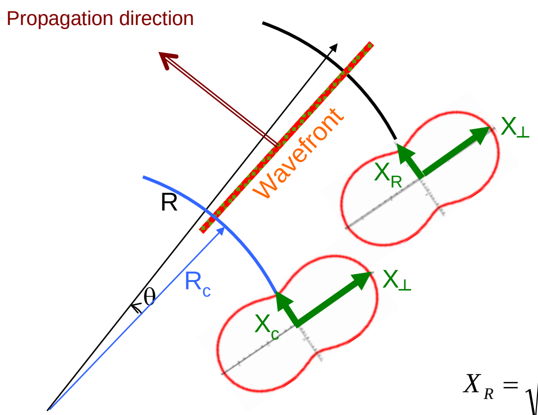


Figure 2: Rotating the principal axis of the tensor impedance matrix excites the propagating mode in that direction, but the wavefront does not rotate in that direction.

The second key discovery was that if in addition we adjusted the local propagation speed through impedance grading along the wavefront, we could make the wavefront turn in any direction. The grading for the principal axis impedance X_R in the propagation direction is shaped such that the electrical path remains constant along a turning wavefront, even though the physical propagation distance is a function of the radius of curvature. Using the fact that surface propagation speed scales with $(1 + X^2)^{-1/2}$, the impedance grading function takes on the form shown in Figure 3.



$$X_R = \sqrt{\left(\frac{R_c}{R}\right)^2 \left(1 + X_c^2\right) - 1}$$

Figure 3: Wavefront (phasefront) is maintained by keeping constant the electrical path length at different radii.

As a demonstration of the high degree of propagation control these two methods afford together, a tensor surface impedance function was derived to make the wavefront launched by a dipole array follow a circular path. Note that confinement of energy to the circular path is achieved **solely** by impedance grading and principal axis rotation, and that no total internal reflection mechanism is used as with surface waveguides which are built as impedance channels.

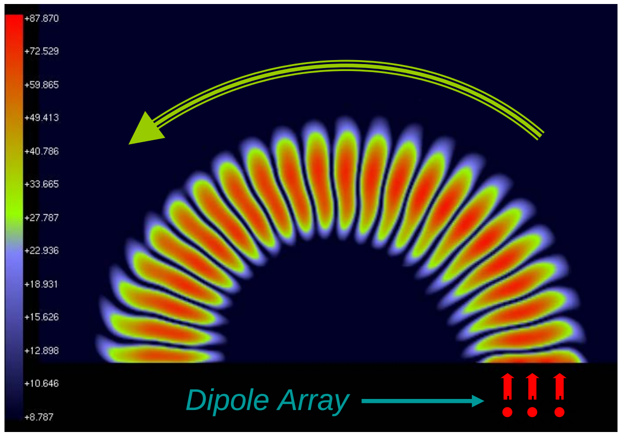


Figure 4: Full propagation control is achieved by combining principal axis rotation with effective impedance grading to maintain constant phase.

This new surface propagation control method opens a wide variety of applications that we have started exploring. It has been used, for instance, to improve the performance of previously reported surface impedance waveguides, by reducing leakage from and maintaining phase in curved sections, as shown in Figure 5. Other applications include designing surface lensing structures for antenna and communications applications, for which we have already very encouraging preliminary results, as shown by the surface impedans lens shown in Figure 6, which converts a point source into a surface plane wave.

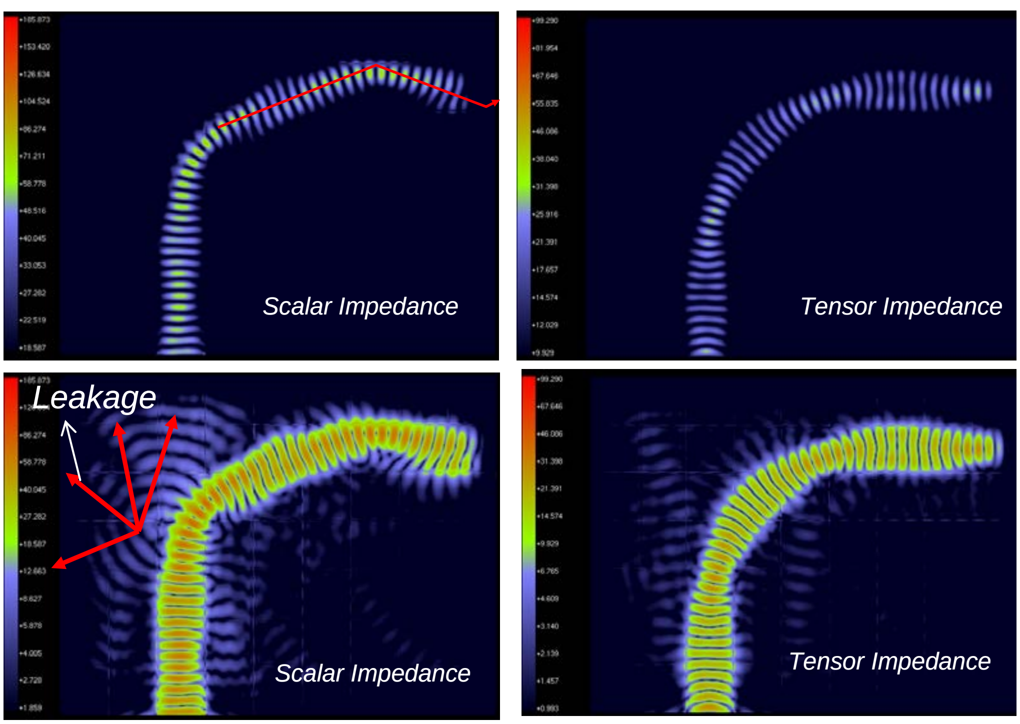


Figure 5: Improved surface waveguide performance through the use of tensor impedance.

We will continue investigating the use of tensor impedance surfaces for propagation and radiation control. We will also study issues related to building such surfaces, including curvature effects, unit cell layout methods, and unit cell performance.

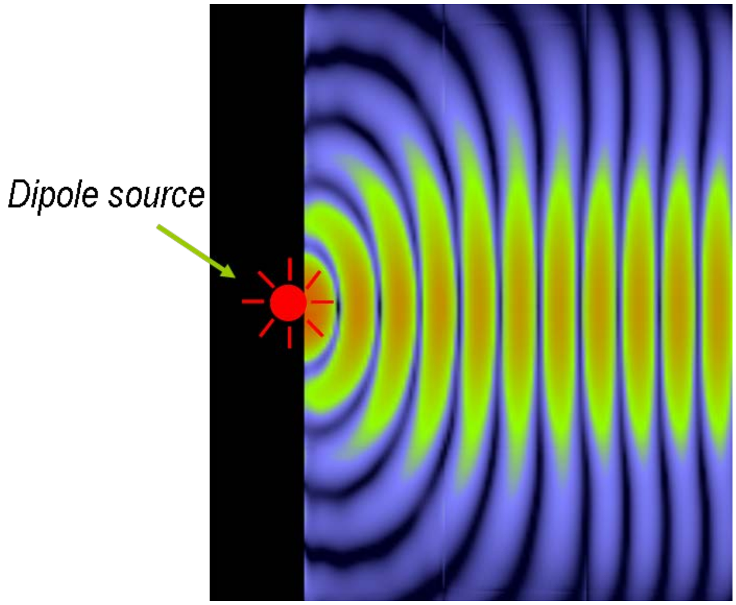


Figure 6: A lensing tensor impedance surface converts a dipole point source to a surface plane wave.